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# Impact of UV-B Radiation Upon Estuarine Microcosms

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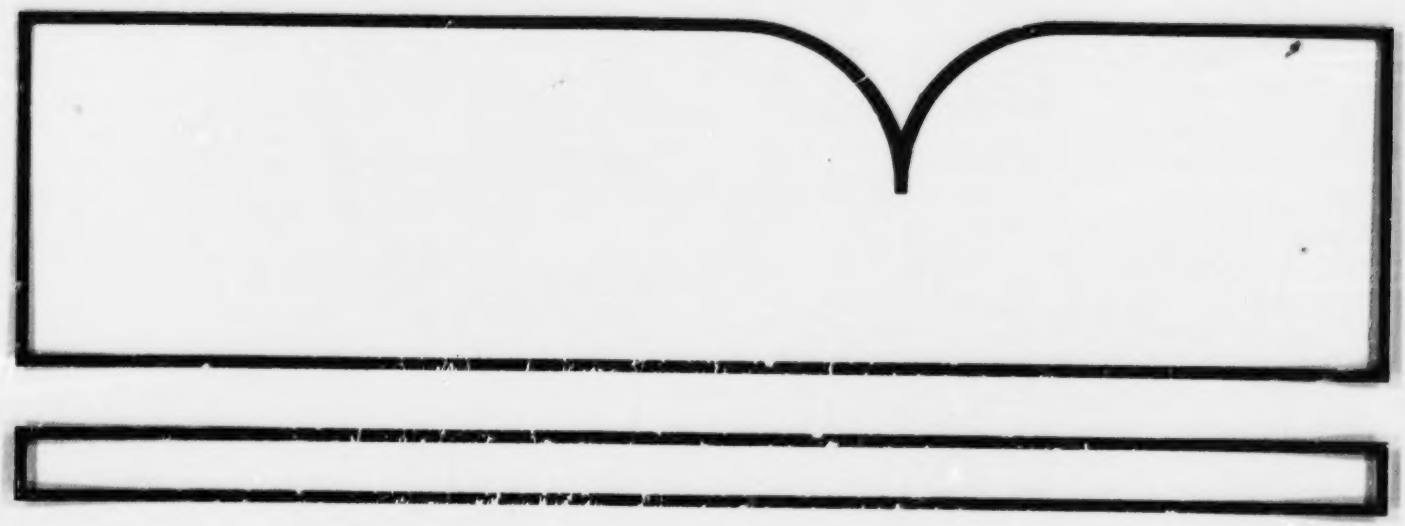

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16. ABSTRACT

Twelve flow-through estuarine microcosms were exposed daily to four different levels of UV-B radiation (290-320nm) ($1.57 \times 10^2$, $.643 \times 10^3$ and $7.61 \times 10^3$ $J \cdot m^{-2} d^{-1}$) in addition to a natural level of visible solar radiation (380 - 800nm). The parameters studied over a four week period were phytoplankton community composition, plankton biomass (ash-free dry weight), chlorophyll a concentration and primary productivity (radiocarbon uptake). With increased exposure to UV-B radiation there was an obvious alteration of the community composition. Daily exposure to enhanced levels of UV-B radiation also depressed the biomass, the chlorophyll a concentration and the radiocarbon uptake of samples from the ecosystems.

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# IMPACT OF UV-B RADIATION UPON ESTUARINE MICROCOSMS

ROBERT C. WORREST, BRUCE E. THOMSON and HENRY VAN DYKE
Department of General Science, Oregon State University, Corvallis, OR 97331, USA

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**Abstract**—Twelve flow-through estuarine microcosms were exposed daily to four different levels of UV-B radiation (290–320 nm) ($1.57 \times 10^2$, $6.43 \times 10^3$, $6.86 \times 10^3$ and $7.61 \times 10^3$ J·m$^{-2}$d$^{-1}$) in addition to a natural level of visible solar radiation (380–800 nm). The parameters studied over a four week period were phytoplankton community composition, plankton biomass (ash-free dry weight), chlorophyll *a* concentration and primary productivity (radiocarbon uptake). With increased exposure to UV-B radiation there was an obvious alteration of the community composition. Daily exposure to enhanced levels of UV-B radiation also depressed the biomass, the chlorophyll *a* concentration and the radiocarbon uptake of samples from the ecosystems.

## INTRODUCTION

Human activities may have the effect of causing a 16% reduction in stratospheric ozone. The resultant 40–50% increase in transmission of DNA-damaging UV radiation in the 290–320 nm waveband (UV-B radiation) at 45 N latitude (NAS, 1979) is cause for concern with respect to the ecological impact upon marine ecosystems. Studies initiated under the Climatic Impact Assessment Program (CIAP) of the U.S. Department of Transportation demonstrate that simulated solar UV radiation can, under experimental conditions, detrimentally affect the marine algae that form the base of the food web of oceanic and estuarine ecosystems. These organisms survive in nature by a combination of mechanisms for tolerating the detrimental effects of UV-B radiation. The key question is whether the potential increase in biologically harmful UV radiation might overwhelm these protective mechanisms and produce changes that will have damaging consequences to the ecosystem.

UV-B radiation (e.g. 310 nm) penetrates approximately the upper 10% of the marine euphotic zone before it is reduced to 1% of its surface irradiance (Jerlov, 1976). Any increase in the surface UV-B fluence would result in a comparable increase throughout the entire water column. The behavioral, morphological and physiological responses of marine organisms which tend to protect them from excessive exposure to biologically harmful UV radiation are cued, most likely, by long-wavelength UV and visible radiation, a waveband which would be unaffected by a partial depletion of stratospheric ozone. Therefore, marine forms which are capable of tolerating present levels of UV-B radiation would lack the cue for a protective response to enhanced levels of UV-B radiation. On the other hand, if organisms do respond to UV-B radiation by downward migration in the water column, they would move to a region of different ecological, chemical and physical properties, including decreased photosynthetically active radiation. Thus, there is a potential for an adverse effect of increased UV-B radiation in either case.

Recently, several researchers (Worrest *et al.*, 1978; Lorenzen, 1979; Calkins and Thordardottir, 1980; Smith and Baker, 1980; Smith *et al.*, 1980; Thomson *et al.*, 1980; Worrest *et al.*, 1980; Worrest *et al.*, 1981) have demonstrated a potential for detrimental effects of solar UV radiation upon primary producers comprising the base of the food web of marine ecosystems. The current study describes the impact of daily exposure to simulated solar UV-B radiation upon seminatural, estuarine ecosystems located within a greenhouse.

## MATERIALS AND METHODS

Twelve naturally derived microcosms were established within a fiberglass greenhouse at the Oregon State University Marine Science Center in Newport, OR (44°37'N/124°03'W). Into each of 3 flow-through cooling tanks, 4 15-ℓ microcosm containers (30 × 27 cm diameter) were immersed to within 4 cm of their tops. The 15-ℓ containers were supported on a rotating turntable (0.25 rpm). The inflow and overflow ports for the containers were designed to allow approximately 15 ℓ of seawater from Yaquina Bay to enter each container daily. The temperature of the seawater was recorded continuously.

The structural fiberglass of the greenhouse filtered out UV radiation from the solar spectrum with wavelengths shorter than 360–380 nm. Experimentally enhanced levels of UV-B radiation were provided by a 3 h exposure to sunlamp/filter systems which utilized cellulose acetate as a 290-nm cut-off filter. The supplemental radiation for one of the ecosystem types was filtered by a 315-nm cut-off filter (0.18 mm thickness of Mylar 'D' polyester film). This ecosystem type served as a control for potential effects of the UV-B spectral region. Three other exposure levels were established by using 3 different thicknesses of cellulose

Correspondence and reprint requests should be sent to Robert C. Worrest.

acetate (0.13, 0.19 and 0.25 mm). Westinghouse FS40 sunlamps were used as the radiation source. Each of the 4 experimental treatments was established within each of the 3 large holding-tanks, yielding a randomized complete block design with 3 replicates of 4 treatments. Prior to the experiment, a month-long baseline study was conducted. In the baseline study the sunlamps for all 12 containers were covered with Mylar 'D' filters.

The irradiance of the ecosystems in the UV region at the surface of the water was measured by means of a modified Gamma Scientific 2900SR spectroradiometer system (Worrest *et al.*, 1978) [Table 1]. Standard lamps traceable to the U.S. National Bureau of Standards were used to determine the radiometric measurements. In addition to the absolute irradiance, biologically weighted irradiances were determined to allow a comparison between the experimental UV-B irradiance and natural levels of UV-B radiation (Table 1). Three biological weighting functions were considered: an action spectrum representing generalized plant responses to UV-B radiation (Caldwell, 1968), a DNA action spectrum (Setlow, 1974), and an action spectrum derived by Jones and Kok (1966) for photoinhibition of isolated chloroplasts. Daily exposure levels of the experimental system were set to represent both reduced and enhanced levels of natural UV-B exposure. The total solar irradiance was measured with an Eppley pyranometer (Model PSP, 281–2800 nm). Daily fluences are illustrated in Fig. 1. Although the irradiance in the 380–800 nm waveband varied markedly, daily supplementation with UV-B radiation was kept constant.

Four parameters of the developing ecosystems were studied over a 4-wk period: phytoplankton community composition, planktonic biomass, chlorophyll *a* concentration and primary productivity (radiocarbon uptake). Although the dominant species found in the baseline study (all microcosms with the same exposure regime) were different from those found during the experimental study, the trends in the parameters of interest were similar to those found in the Mylar-control microcosms during the experimental study. The fact that the baseline study and the ex-

Table 1. Daily fluence as measured by means of a modified Gamma Scientific 2900SR Spectroradiometer System (Worrest *et al.*, 1978)

| | Absolute fluence ($J \cdot m^{-2} \cdot d^{-1}$) | | | |
|---|---|---|---|---|
| Wavelength (nm) | Mylar 'D' (0.18 mm) | Cellulose acetate (0.25 mm) | Cellulose acetate (0.19 mm) | Cellulose acetate (0.13 mm) |
| 290 | | 0.240 | 0.338 | 1.23 |
| 291 | | 0.650 | 1.16 | 3.46 |
| 292 | | 1.84 | 3.08 | 9.44 |
| 293 | | 5.03 | 8.93 | 23.3 |
| 294 | | 15.2 | 24.8 | 52.3 |
| 295 | | 31.0 | 43.8 | 78.1 |
| 296 | | 58.2 | 77.2 | 116 |
| 297 | | 85.1 | 107 | 147 |
| 298 | | 117 | 135 | 175 |
| 299 | | 133 | 153 | 189 |
| 300 | | 161 | 181 | 216 |
| 301 | | 195 | 216 | 245 |
| 302 | | 231 | 248 | 279 |
| 303 | | 252 | 269 | 297 |
| 304 | | 266 | 286 | 311 |
| 305 | | 278 | 293 | 322 |
| 306 | | 295 | 312 | 332 |
| 307 | | 302 | 318 | 346 |
| 308 | | 311 | 325 | 351 |
| 309 | | 311 | 327 | 350 |
| 310 | | 311 | 326 | 349 |
| 311 | | 311 | 326 | 349 |
| 312 | ND* | 310 | 325 | 348 |
| 313 | 0.252 | 434 | 450 | 481 |
| 314 | 0.781 | 310 | 323 | 346 |
| 315 | 2.40 | 310 | 323 | 346 |
| 316 | 6.32 | 309 | 322 | 345 |
| 317 | 22.1 | 309 | 321 | 343 |
| 318 | 36.9 | 309 | 325 | 346 |
| 319 | 53.1 | 309 | 326 | 343 |
| 320 | 70.4 | 311 | 324 | 340 |
| 330 | 140 | 242 | 253 | 267 |
| 340 | 91.0 | 133 | 139 | 144 |
| 350 | 58.3 | 80.7 | 85.8 | 89.6 |
| *Total* | | | | |
| Absolute | $3.12 \times 10^3$ | $1.21 \times 10^4$ | $1.28 \times 10^4$ | $1.39 \times 10^4$ |
| 'Plant' weighted | 0.0 | 464 | 522 | 636 |
| 'DNA' weighted | 0.0 | 56.5 | 67.6 | 93.1 |
| 'PI' weighted | $8.42 \times 10^2$ | $4.43 \times 10^3$ | $4.72 \times 10^3$ | $5.17 \times 10^3$ |

*ND = not determined. Absolute irradiance was less than maximum sensitivity of instrument ($< 10^{-5}$ W $\cdot$ m$^{-2}$).

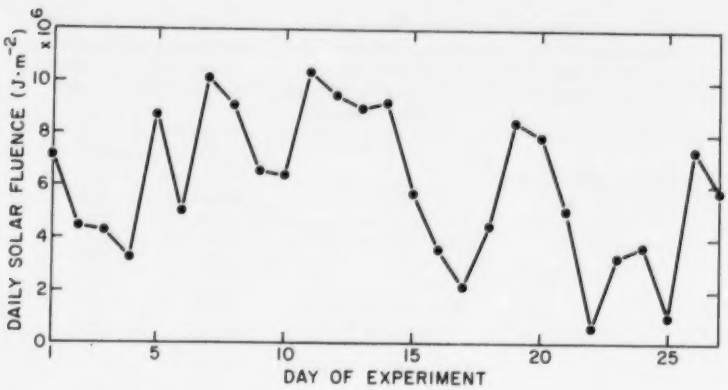


Figure 1. Daily solar fluence in the 281–2800 nm waveband during the period of the current experiment. The irradiance was measured with an Eppley pyranometer (Model PSP).

perimental study recruited organisms from Yaquina Bay at different times would explain the species differences between the two studies. No significant differences in the 4 parameters were found among 4 groups of 3 replicates in the baseline study. Therefore, any differences found in the experimental study presumably are due to differences in exposure to UV-B radiation. Diatoms were found to be, by far, the most abundant constituent of the plankton communities; therefore, phytoplankton samples were prepared by the method described by Hendey (1974), a method specific for diatoms. Approximately 500 organisms in each sample were evaluated taxonomically. Two indices of diversity were utilized for an analysis of community composition: an estimate of the Shannon–Wiener uncertainty measure ($H''$) expressed as nats per individual (McIntosh, 1967) and a measure of redundancy ($R'$). $H''$ ranges from 0 ($\log_e 1$), if all of the individuals in the assemblage are of one taxon, to $\log_e N$, if the number of taxa equals the number of individuals. The more taxa there are and the more nearly equal their proportions, the greater the uncertainty of predicting the taxon of the next individual to be observed, and therefore, the greater the diversity. $H''$, being an estimator, is subject to sampling error (Pielou, 1966).

The redundancy index expresses the degree of dominance in a given sample relative to the partitioning of individuals among the taxa. Values of $R'$ range from 0, when the individuals are equally distributed among the taxa, to 1, when all but one taxon are represented by a single individual. Computer programs were used to calculate the uncertainty measure and the redundancy index.

Productivity of the planktonic constituents of the ecosystems were assessed by the traditional carbon-14 light and dark bottle technique utilizing quartz bottles. Each bottle was prepared in duplicate. The bottles were filled to within 5 m/ of the top with samples from near the bottom of the microcosms. The cultures were then inoculated with 5 $\mu$Ci of [$^{14}$C]-sodium bicarbonate (New England Nuclear) and positioned horizontally near the bottom of the microcosms for a period of 3 h. Following the exposure period aliquots from each bottle were membrane filtered (0.45 $\mu$m porosity, Millipore Corporation) at 1/3 atm vacuum, fumed with HCl, and desiccated over indicating silica gel and soda lime. The radiocarbon uptake was ascertained by utilizing a liquid scintillation counter (Beckman LS8000 three-channel liquid scintillation system with Compton distribution external standardization). Ready-Solv HP (Beckman Instruments) was used as the fluor. During the exposure period samples were taken from the ecosystem tanks and analyzed for total carbonate content and chlorophyll *a* concentration.

Phytoplankton extracts were analyzed for chlorophyll *a* concentration by the SCOR/UNESCO technique. The samples were processed in subdued light. They were filtered at 1/6 atm through 4.5 cm Whatman GF/C glass filters which had been coated with magnesium carbonate. The samples were then homogenized with a Brinkman Polytron for less than 30 s, extracted in the dark in fresh 90% aqueous spectrophotometric grade acetone for 20 min with regular mixing, centrifuged in swing-out tubes, and measured immediately by spectrophotometer at 750, 663, 645 and 630 nm against a 90% acetone blank. A Coleman Model 124D double-beam recording spectrophotometer with a 10 cm cell-path-length capability was utilized.

Planktonic biomass (ash-free dry wt) was determined by desiccating samples on standard GF/C glass filters over a drying agent, weighing, and then ashing the samples at 475°C to complete the organic weight determinations.

## RESULTS

Obvious changes occurred in the community composition following daily exposure to the 4 levels of UV-B radiation (Tables 2 and 3). Of note was the increase in the final percentage composition of *Chaetoceros* sp. No. 1 with increased levels of UV-B exposure, accompanied by a decrease in the percentage composition of *Skeletonema costatum*. Any increase in community diversity *with time* reflects the potential recruitment of new species as the experiment progresses, while previously recruited species establish themselves in the microcosms.

Daily exposure to enhanced levels of UV-B radiation also depressed the biomass, chlorophyll *a* concentration, and radiocarbon uptake of samples from the ecosystems (Table 4 and Fig. 2). The results of analyses of covariance are illustrated in Table 5 for testing the slopes and elevations of the regression lines plotted in Fig. 2.

## DISCUSSION

As determined from the work of Van Dyke and Thomson (1975), alteration of an algal community structure may result from exposure of microcosms to

Table 2. A list of the dominant diatom species (≥ 5% of the total number of enumerated diatoms within any treatment) and the percentage composition of those species within each assemblage. The seminatural ecosystems were allowed to develop 4 wk, with samples collected at the beginning and end of the experiment

| Fluence (290–350 nm) ($J \cdot m^{-2} \cdot d^{-1}$) | Taxon | Percentage composition | |
|---|---|---|---|
| | | Initial | Final |
| $3.12 \times 10^3$ | *Chaetoceros* No. 1 | 53.4 | 33.2 |
| | *C.* No. 2 | 0.8 | 1.5 |
| | *C.* No. 5 | 6.0 | 3.1 |
| | *Skeletonema costatum* | 7.1 | 33.4 |
| | *Thalassiosira* No. 2 | 15.5 | 5.1 |
| $1.21 \times 10^4$ | *Chaetoceros* No. 1 | 47.2 | 39.5 |
| | *C.* No. 2 | 0.4 | 10.2 |
| | *C.* No. 5 | 0.6 | 1.5 |
| | *Skeletonema costatum* | 25.3 | 16.3 |
| | *Thalassiosira* No. 2 | 9.8 | 11.9 |
| $1.28 \times 10^4$ | *Chaetoceros* No. 1 | 62.7 | 57.7 |
| | *C.* No. 2 | 3.4 | 0.3 |
| | *C.* No. 5 | 0.0 | 10.6 |
| | *Skeletonema costatum* | 13.5 | 14.7 |
| | *Thalassiosira* No. 2 | 8.4 | 5.2 |
| $1.39 \times 10^4$ | *Chaetoceros* No. 1 | 55.9 | 73.5 |
| | *C.* No. 2 | 3.9 | 0.3 |
| | *C.* No. 5 | 0.0 | 4.0 |
| | *Skeletonema costatum* | 10.2 | 3.5 |
| | *Thalassiosira* No. 2 | 15.2 | 11.9 |

enhanced levels of UV-B radiation. A similar impact of UV-B radiation on the community structure of marine microcosms was noted by Worrest *et al.* (1978). Also noted in the latter study were depressed chlorophyll *a* concentrations, reduced biomass, and increased autotrophic indices. Both of these studies utilized artificial (relatively low-level) light sources in the laboratory; whereas in the current investigation, microcosms were exposed to about 90% of the natural, visible fluence. The results of the current investigation parallel those found by Worrest *et al.* (1978) and Van Dyke and Thomson (1975), which, in part, corroborates the previous laboratory results.

Although the microcosms in the current investigation were exposed to natural, solar radiation in the 360–800 nm waveband, the artificial UV-B source did not conform exactly to the shape of the solar UV-B spectrum at 44°37'N latitude. The artificial source was weighted slightly, but significantly, heavier at the shorter wavelengths (e.g. 290 nm). Due to this lack of conformity, and because not all wavelengths of UV radiation are equally effective in producing biological effects, the relative biological effectiveness of radiation in the UV waveband was determined in order to compare the results of the present study with what might occur in nature. Photobiological action spectra demonstrate the relationship between biological effectiveness and wavelength of incident radiation. Analytic representations of action spectra can then be used to weight the spectral irradiance of interest. Weighting

Table 3. Analysis of community composition

| *Filter* | *N* | | *S* | | *H″* (nats) | | *R′* | |
|---|---|---|---|---|---|---|---|---|
| | *Initial* | *Final* | *Initial* | *Final* | *Initial* | *Final* | *Initial* | *Final* |
| Mylar | 504 | 503 | 17 | 37 | 1.619 | 2.831 | 0.466 | 0.311 |
| 0.25 mm CA | 502 | 502 | 23 | 22 | 1.691 | 1.653 | 0.512 | 0.563 |
| 0.19 mm CA | 500 | 503 | 17 | 19 | 1.381 | 1.645 | 0.558 | 0.554 |
| 0.13 mm CA | 508 | 500 | 21 | 11 | 1.568 | 1.224 | 0.535 | 0.595 |

The seminatural ecosystems were allowed to develop 4 wk, with samples collected at the beginning and end of the experiment. The filters used in the exposure apparatus were a 0.18 mm thickness of Mylar 'D' and 3 different thicknesses of cellulose acetate (CA). *N* is the number of diatoms in the sample, *S* is the number of species represented in the sample, *H″* is the estimator for the uncertainty index, and *R′* is a measure of redundancy. Estimate of sample variance for *H″* in all cases was in the 0.003–0.004 range.

Table 4. Biomass (ash-free dry wt), chlorophyll *a* concentration, and radiocarbon uptake for plankton samples (±SD). Some samples were taken from the water flowing into the ecosystem containers

| Day | Filter | Biomass ($mg \cdot m^{-3}$) | Chlorophyll *a* ($mg \cdot m^{-3}$) | Radiocarbon uptake ($mgC \cdot m^{-3} \cdot h^{-1}$) |
|---|---|---|---|---|
| 5 | Intake | 804 ± 5 | 1.33 ± 0.12 | ND* |
| | Mylar | 722 ± 12 | 1.27 ± 0.16 | 1.23 ± 0.20 |
| | 0.25 mm CA | 756 ± 41 | 1.40 ± 0.13 | 1.17 ± 0.28 |
| | 0.19 mm CA | 684 ± 66 | 1.36 ± 0.02 | 1.31 ± 0.13 |
| | 0.13 mm CA | 705 ± 17 | 1.30 ± 0.10 | 1.09 ± 0.27 |
| 12–15 | Intake | 1120 ± 116 | 1.97 ± 0.14 | ND |
| | Mylar | 858 ± 25 | 2.03 ± 0.12 | 1.57 ± 0.11 |
| | 0.25 mm CA | 836 ± 15 | 1.87 ± 0.07 | 1.59 ± 0.18 |
| | 0.19 mm CA | 628 ± 64 | 1.88 ± 0.12 | 1.43 ± 0.04 |
| | 0.13 mm CA | 612 ± 21 | 1.51 ± 0.14 | 1.27 ± 0.24 |
| 20 | Intake | 1016 ± 77 | | |
| | Mylar | 640 ± 18 | | |
| | 0.25 mm CA | 497 ± 125 | ND | ND |
| | 0.19 mm CA | 411 ± 22 | | |
| | 0.13 mm CA | 335 ± 13 | | |
| 26–27 | Intake | 1238 ± 87 | 3.45 ± 0.06 | ND |
| | Mylar | 772 ± 29 | 2.55 ± 0.05 | 4.07 ± 0.20 |
| | 0.25 mm CA | 515 ± 44 | 1.94 ± 0.09 | 2.21 ± 0.13 |
| | 0.19 mm CA | 418 ± 9 | 1.01 ± 0.14 | 1.26 ± 0.18 |
| | 0.13 mm CA | 337 ± 41 | 1.05 ± 0.08 | 1.09 ± 0.27 |

*ND = not determined.

the irradiance over all wavelengths yields the biologically effective irradiance which, when summed over time, gives the biologically effective fluence.

This approach presupposes knowledge of the action spectrum of interest. Usually the selection of a weighting function occurs 'after-the-fact' by determining which of the published action spectra best 'fits' the data in question; not an unrealistic approach if there are no other practical alternatives. For example, Smith and Baker (1980) and Smith *et al.* (1980) have demonstrated that results of acute radiocarbon-uptake studies are consistent with a photoinhibition action spectrum (Jones and Kok, 1966), but results of chronic exposures (Wolniakowski, 1980) appear to be best described by an analytic representation (Green and Miller, 1975) of a DNA action spectrum (Setlow, 1974). The results of the present study were evaluated utilizing the absolute fluence as well as three different biologically effective fluences: one weighted by a generalized plant action spectrum (Caldwell, 1968), another by a DNA action spectrum (Setlow, 1974) and the third by a photoinhibition action spectrum (Jones and Kok, 1966).

The final results of the chlorophyll, radiocarbon-uptake and biomass studies were regressed (least-squares linear regression) against each of the four previously mentioned methods of expressing the experimental UV fluence (Table 6). All of the regression models had highly significant coefficients of correlation ($r^2$), but there was a trend favoring the biological sensitivity functions weighted more heavily at the shorter wavelengths (plant and DNA) rather than the photoinhibition action spectrum which has a 'flatter' response or a response more closely resembling the absolute irradiance spectrum. Table 6 shows that the weighting function with the best fit for the chlorophyll and radiocarbon-uptake responses to UV-B radiation is the generalized plant action spectrum. For the biomass response the DNA action spectrum fits best. The reason for the different types of responses might be that chlorophyll and radiocarbon uptake are direct measures of phytoplankton activity; whereas biomass is a measure of both phyto- and zooplankton content.

The present experiment, which took place in the fall, can be related to natural conditions by making use of the atmospheric model formulated by Green *et al.* (1980). The microcosms exposed to UV radiation filtered by a 0.25 mm thickness of cellulose acetate (CA) had daily fluences of 464.1 $Eff_{Plant}$ $J \cdot m^{-2}$, which is comparable to the daily fluence (464.5 $Eff_{Plant}$ $J \cdot m^{-2}$) on 1 October at 44°37'N latitude with 0.295 cm ozone, 0.0 albedo, and a 2.0 aerosol scaling factor at sea level and utilizing Model C (parameters described by Green *et al.*, 1980). The daily fluence under the 0.19 mm thickness of CA (521.7 $Eff_{Plant}$ $J \cdot m^{-2}$) is comparable to a 5.5% decrease in ozone in the model previously described, and the daily fluence under the 0.13 mm thickness of CA (636.1 $Eff_{Plant}$ $J \cdot m^{-2}$) is comparable to a 15% decrease in ozone. The results illustrated in Fig. 2 and Table 5 demonstrate that it would be difficult to detect any stress upon the microcosms following a 5.5% decrease in stratospheric ozone below current levels (0.25 mm CA vs 0.19 mm CA), but a 15% decrease in stratospheric

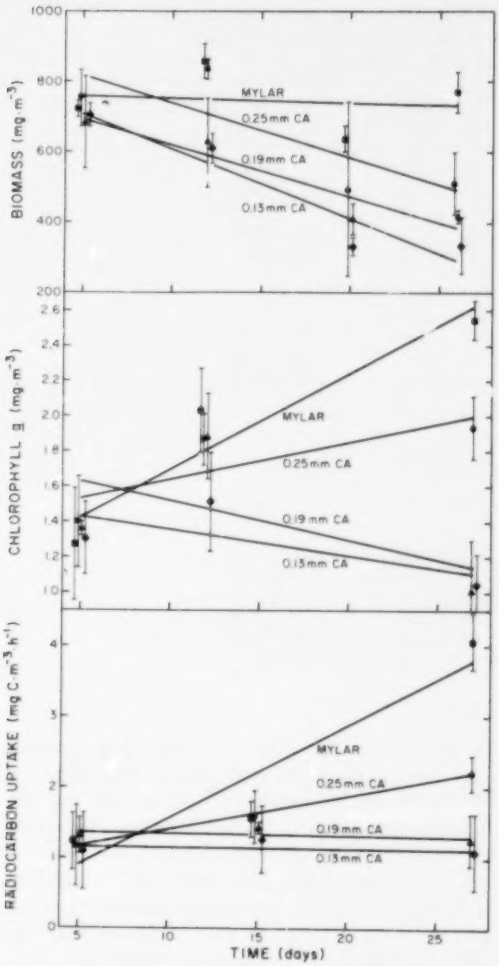


Figure 2. Least-squares regression analysis of biomass (ash-free dry wt), chlorophyll *a* concentration and radiocarbon uptake following exposure to UV-B enhanced solar radiation. Filters used were a 0.18 mm thickness of Mylar 'D' and 3 different thicknesses of cellulose acetate (CA). Error bars represent 95% confidence intervals.

ozone would have a significant impact (0.25 mm CA vs 0.13 mm CA). The impact of UV-B radiation upon community composition follows a similar pattern (Table 3).

The interpretation of changes in community diversity is subject to speculation, but one can say that, if the species composition of the primary producers is altered, the quality and possibly the quantity of food present for primary consumption could also be altered. Therefore, organic carbon exchange between trophic levels could be affected. The impact would be significant if the organisms selected for by enhanced UV-B radiation were of lower nutritional value (i.e. if they impacted the growth and fecundity of the consumers). Another effect might be to alter the size distribution of the component producers in the ecosystem. Decreasing the size of the representative diatoms upon which consumers graze can significantly increase the energy allotment required for consumption, thereby reducing the feeding efficiency of the consumer. On the other hand, changes in the phytoplankton species composition might be beneficial to primary producer–consumer trophodynamics. The actual impact is subject to further investigation.

As previously stated by Steemann Nielsen (1964) and Jitts *et al.* (1976), there is good evidence that current levels of solar UV radiation are stressful to marine primary productivity. When organisms recruited from Yaquina Bay (where the daily fluence at the surface was about 465 $Eff_{Plant}$ $J \cdot m^{-2}$) were cultured in the microcosms shielded from UV-B radiation (Mylar filter, 0.0 $Eff_{Plant}$ $J \cdot m^{-2} \cdot d^{-1}$) the chlorophyll *a* content and radiocarbon uptake increased significantly. The measure of biomass did not show any significant trend, however, indicating a rapid turnover of organic matter by the consumers. The microcosms exposed to UV-B radiation demonstrated various levels of stress (Fig. 2). If the indirect impact of suppression of primary production upon consumers is linear, a 5% reduction of primary production would result in a 5% reduction in fish production. A question still under investigation is whether the trophodynamic relationships might be nonlinear. For example, there may be an amplification factor involved resulting in a relatively greater impact at higher trophic levels then at the primary-producer level.

All the results in the present study are from microcosms about 30 cm in depth. Great caution must be exercised when relating these results to a natural body of water. To be considered are such factors as the depth of the attenuating water column, mixing, the ratio of photosynthetically active radiation to UV-B radiation, behavioral responses and the prehistory of

Table 5. Results of analyses of covariance testing for significant differences (5% level) between slopes and between elevations of regression lines plotted in Fig. 2

| | Filter | | |
|---|---|---|---|
| Filter | 0.25 mm CA | 0.19 mm CA | 0.13 mm CA |
| Mylar | *C* + −<br>*U* + −<br>*B* + + | *C* + +<br>*U* + −<br>*B* + + | *C* + +<br>*U* + +<br>*B* + + |
| 0.25 mm CA | | *C* + −<br>*U* + −<br>*B* − + | *C* + +<br>*U* + +<br>*B* − + |
| 0.19 mm CA | | | *C* − −<br>*U* − −<br>*B* − − |

*C*, *U* and *B* represent chlorophyll concentration, radiocarbon uptake, and biomass, respectively. + indicates that there is a significant difference between the 2 respective treatments ($P \leq 0.05$); − indicates that $P > 0.05$. The first of the pair of ± signs is the test of slopes, and the second is the test of elevations.

Table 6. Tests of least-squares linear regression for chlorophyll *a* content ($C$), radiocarbon uptake ($U$), and biomass ($B$) against UV fluence (absolute fluence and biologically weighted fluences)

| Weighting function | Coefficient of correlation ($r^2$)* | Matrix of probabilities from $F$-tests of residual mean squares | | |
|---|---|---|---|---|
| | | DNA | PI | Absolute |
| Plant | $C = 0.83$ | $P_C = 0.46$ | $P_C = 0.28$ | $P_C = 0.28$ |
| | $U = 0.96$ | $P_U = 0.25$ | $P_U = 0.20$ | $P_U = 0.19$ |
| | $B = 0.95$ | $P_B = 0.36$ | $P_B = 0.19$ | $P_B = 0.17$ |
| DNA | $C = 0.82$ | | $P_C = 0.32$ | $P_C = 0.31$ |
| | $U = 0.94$ | | $P_U = 0.44$ | $P_U = 0.42$ |
| | $B = 0.96$ | | $P_B = 0.11$ | $P_B = 0.10$ |
| PI | $C = 0.75$ | | | $P_C = 0.49$ |
| | $U = 0.93$ | | | $P_U = 0.49$ |
| | $B = 0.92$ | | | $P_B = 0.47$ |
| Absolute | $C = 0.75$ | | | |
| | $U = 0.93$ | | | |
| | $B = 0.91$ | | | |

*All of the regression models had highly significant coefficients of correlation ($P < 0.001$).

The biological weighting functions are based on work by Caldwell (1968) ('Plant'), Setlow (1974) ('DNA'), and Jones and Kok (1966) ('PI').

the target organisms. Although near-surface organisms are impacted by UV-B radiation, the impact on the total, productive water column is still open to question.

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## REFERENCES

Caldwell, M. M. (1968) *Ecol. Monogr.* **38,** 243–268.
Calkins, J. and T. Thordardottir (1980) *Nature* **283,** 563–566.
Green, A. E. S., K. R. Cross and L. A. Smith (1980) *Photochem. Photobiol.* **31,** 59–65.
Green, A. E. S. and J. H. Miller (1975) In *Impacts of Climatic Change on the Biosphere, Part 1: Ultraviolet Radiation Effects* (Edited by D. S. Nachtwey *et al.*), pp. 2-60–2-70. U.S. Dept. Transportation, DOT-TST-75-55, Washington, DC.
Hendey, N. I. (1974) *Microscopy* **32,** 423–426.
Jerlov, N. G. (1976) In *Marine Optics*, pp. 127–150. Elsevier, Amsterdam.
Jitts, H. R., A. Morel and Y. Saijo (1976) *Aust. J. Mar. Freshwater Res.* **27,** 441–454.
Jones, L. W. and B. Kok (1966) *Plant Physiol.* **41,** 1037–1043.
Lorenzen, C. J. (1979) *Limnol. Oceanogr.* **24,** 1117–1120.
McIntosh, R. P. (1967) *Ecology* **48,** 392–404.
NAS, Committee on Impacts of Stratospheric Changes (1979) In *Protection Against Depletion of Stratospheric Ozone by Chlorofluorocarbons*, p. 62. National Academy of Sciences, Washington, DC.
Pielou, E. C. (1966) *Am. Nat.* **100,** 463–465.
Setlow, R. B. (1974) *Proc. Natl. Acad. Sci. USA* **71,** 3363–3366.
Smith, R. C. and K. S. Baker (1980) *Science* **208,** 592–593.
Smith, R. C., K. S. Baker, O. Holm-Hansen and R. Olson (1980) *Photochem. Photobiol.* **31,** 585–592.
Steemann Nielsen, E. (1964) *J. Cons. Int. Explor. Mer.* **29,** 130–135.
Thomson, B. E., R. C. Worrest and H. Van Dyke (1980) *Estuaries* **3,** 69–72.
Van Dyke, H. and B. E. Thomson (1975) In *Impacts of Climatic Change on the Biosphere, Part 1: Ultraviolet Radiation Effects* (Edited by D. S. Nachtwey *et al.*), pp. 5-95–5-113. U.S. Dept. Transportation DOT-TST-75-55, Washington, DC.
Wolniakowski, K. U. (1980) M. S. Thesis, Oregon State University.
Worrest, R. C., D. L. Brooker and H. Van Dyke (1980) *Limnol. Oceanogr.* **25,** 360–364.
Worrest, R. C., H. Van Dyke and B. E. Thomson (1978) *Photochem. Photobiol.* **27,** 471–478.
Worrest, R. C., K. U. Wolniakowski, J. D. Scott, D. L. Brooker, B. E. Thomson and H. Van Dyke (1981) *Photochem. Photobiol.* **33,** 222–227.